Data Assimilation in Ocean Prediction

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LONG-TERM GOALS

Remotely sensed satellite observations provide ocean altimetry data at high temporal and spatial resolutions to an unprecedented accuracy of approximately 5 cms. Availability of data of such high quality and wide coverage makes it possible to address a variety of scientific questions related to physical oceanography including, for example, the accurate estimation of ocean circulation at several levels of interest. Achieving such an objective, however, presents daunting challenges in terms of the enormous size of the problems to be solved. By developing computationally efficient techniques for the direct assimilation of satellite altimetry data, this project aims at improving the reconstruction of ocean fields in global and mesoscale ocean circulation applications, and, therefore, improve the capability of nowcast and forecast Navy models.

OBJECTIVES

The objective of this project is to interface fast implementations of the Kalman-Bucy filters (KBf) that we have developed [1, 2, 3, 4], with the Naval Research Laboratory (NRL) Layered Ocean Model (NOARL), [5], and then carry out extensive data assimilation studies in ocean circulation. We are working in close collaboration with Dr. Harley Hurlburt and Ms. Tommy Townsend at the NRL Stennis Space Center. The research will provide a better understanding of ocean circulation by assimilating satellite altimetry data to global ocean circulation at different levels of resolution.

APPROACH

Our data assimilation approaches are based on the Kalman Bucy filter (KBf). The algorithms we use take advantage of the unique aspects associated with ocean circulation fields, namely: (i) the ocean circulation fields are obtained from the discretization of partial differential equations (dPDE), i.e., the field values at a particular spatial location (site) are mostly related to the field values at the neighboring sites; and (ii) the satellite measurements are extremely sparse.

The local nature of the dPDE model is naturally reflected in the block banded structure of the system matrices, with blocks themselves being banded and sparse. By coupling this block structure with the sparse measurements, we obtain computationally efficient and exact implementations of the KBf, reducing the computational complexity of the KBf by a factor equal to the linear dimension I of the field. To reduce further the computational complexity, we assume that the error field associated with the KBf is a Markov random field (Mrf), i.e., the error field at a particular site and at each time instant is essentially determined by its values in the neighboring sites. This simplifies the error information matrix associated with the filter to a banded block parameterization. The resulting approximate

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implementations of the KBf provide an overall improvement of a factor of I^2 in the computational complexity over the direct implementation of the KBf. The storage requirements are also reduced by an order of I.

WORK COMPLETED

The primary tasks completed in the last year are the extensive testing of the Mrf based KBf data assimilation algorithm with a suite of simple but realistic linear ocean circulation problems. In particular, we have assimilated altimetry data to the Beta-plane model, and to a simplified version of the NRL layered Ocean Model (NOARL) in spherical coordinates that is suitable for a large basin or a global domain. Spherical geometry requires careful treatment of the equations of fluid dynamics to ensure spurious terms are not introduced during the layer averaging process, particularly in the momentum diffusion expressions. Derivation of the data assimilation algorithm for the NOARL model in spherical coordinates is complete, and twin experiments on a 1/2 degree, two and a half layer hydrodynamic model with analytical winds have been run. Prediction errors and the algorithm performance were evaluated for different updating strategies, initial conditions, and data sampling.

In the near future, we plan to test more general basins with realistic coastlines and topography, and with real satellite data collected from Topex / Poseidon. We plan also to consider extensions with thermodynamic conditions.

RESULTS

Twin experiments were run to demonstrate the usefulness of the data assimilation techniques. Here we present results from a two and a half layer nonlinear NOARL run that assimilated simulated TOPEX / POSEIDON sea surface height (SSH). Figures 1, 2, and 3 show estimates of the sea surface height (SSH) for the top layer at day 36 after three complete Topex / Poseidon repeat cycles. The satellite provides highly sparse data. Figure 1 is the simulated real condition or the “truth”, figure 2 is the field after data assimilation, and figure 3 is the spin up with no data assimilation, referred to as the deterministic run. Both mesh and contour plots are plotted in each case.

A visual comparison of the figures illustrates that the SSH image associated with the satellite scanned sparse data is a better estimate of the actual ocean state condition, in our case, the real world run, than the field predicted with no data assimilation. The latter is the low pass version of the actual SSH. The satellite assimilated SSH incorporates the finer details like anomalies as, for example, the valleys and the peaks in figures 1 and 2 that are smoothed out in figure 3.

In figure 4, we present the mean square error (MSE) plots for the SSH averaged over the total field for the 36 day experiment. The MSE for the deterministic run is shown in blue and the MSE for the data assimilated field is in green. The figure displays the significant reduction in MSE provided by the data assimilated KBf algorithm.

IMPACT/APPLICATIONS

This project is in close collaboration with the research group of Dr. Hurlburt at the NRL Stennis Research Center. Our goal is to develop efficient data assimilation algorithms and to interface them with the sophisticated accurate ocean circulation models developed by Dr. Hurlburt and his collaborators at the NRL Stennis Center. We believe this work will lead to improved ocean forecasts that can be used with the Navy fleet nowcast and forecast programs.

TRANSITIONS

The algorithms and software being developed are being made available to NRL.

RELATED PROJECTS

Prof. Igor Shulman of the University of Sourthern Mississippi and Dr. Ole Martin Smedstad of the Planning Systems Inc. are working on the development of data assimilation techniques, [7], based on nudging with the Navy layered ocean model.

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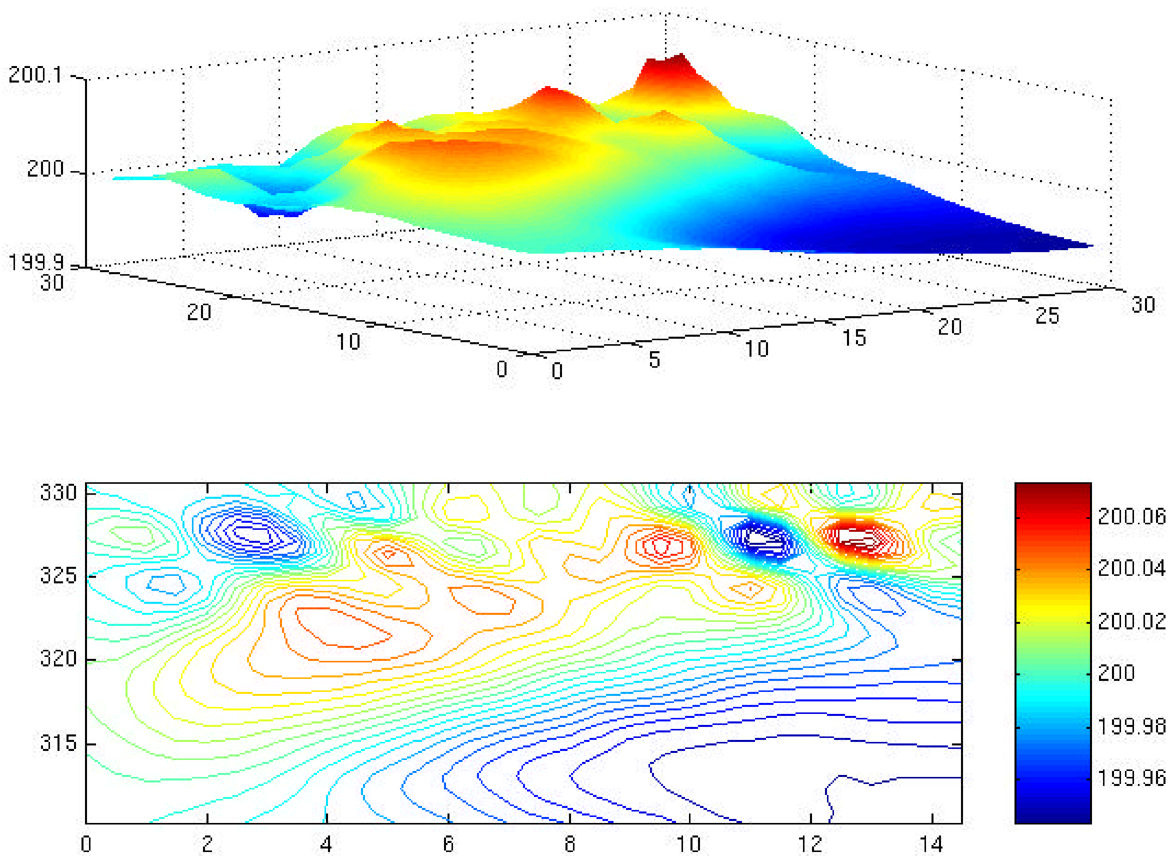

Figure 1: Mesh and contour plots of the sea surface height of the top layer obtained from the "real world run".

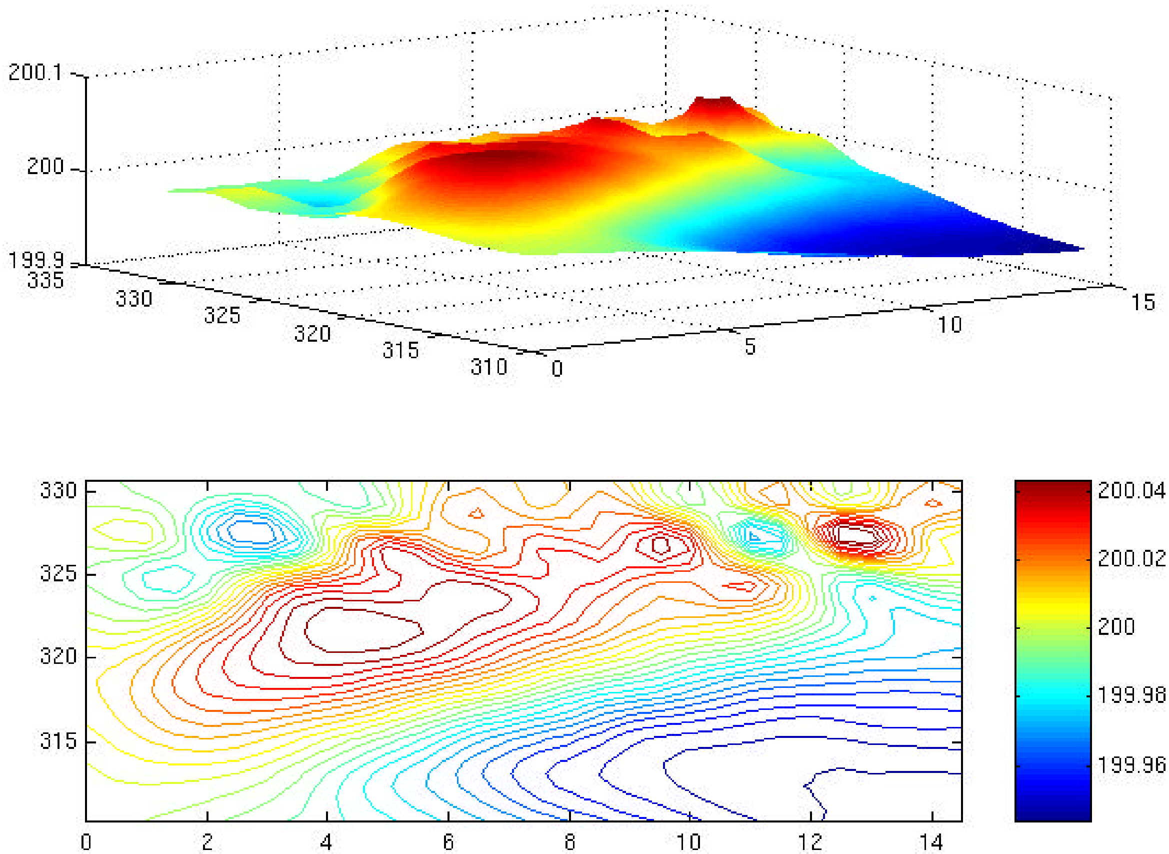

Figure 2: Mesh and contour plots of the sea surface height of the top layer obtained after assimilation of Topex / Poseidon data.

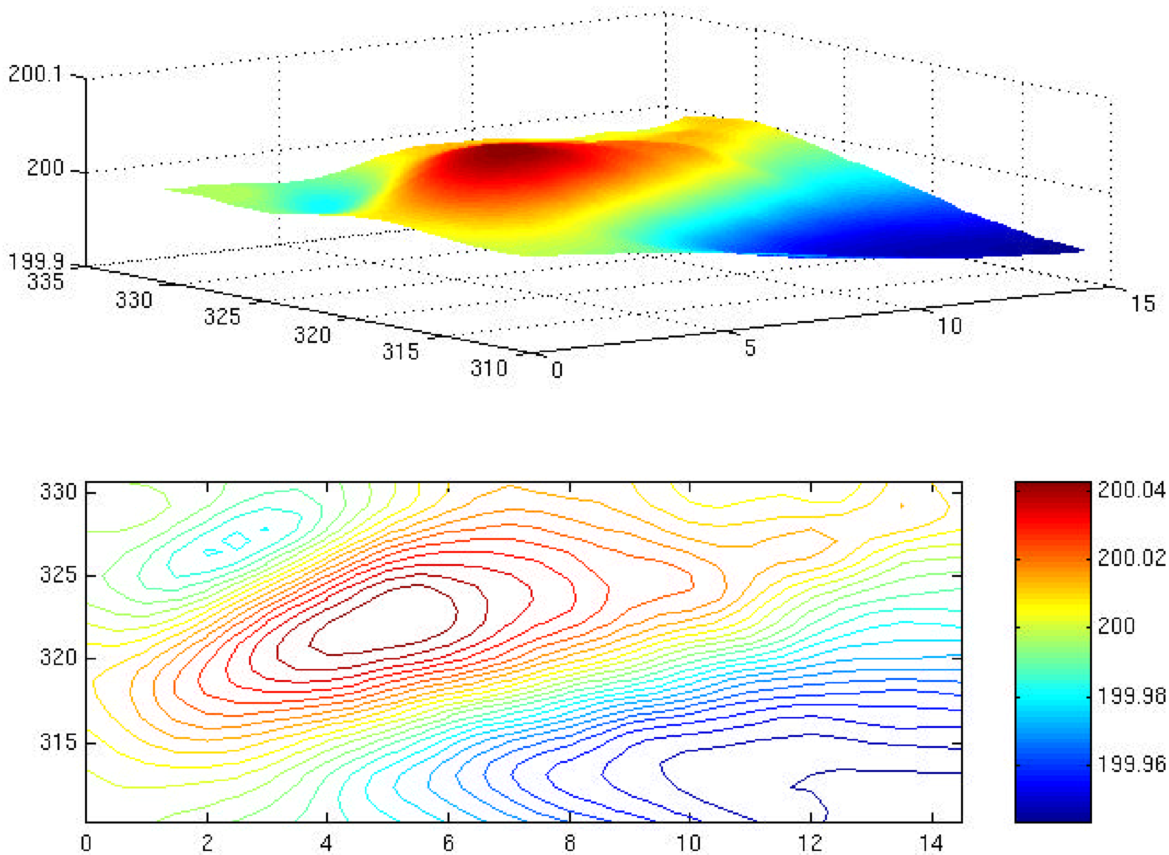

Figure 3: Mesh and contour plots of the sea surface height of the top layer with no data assimilation.

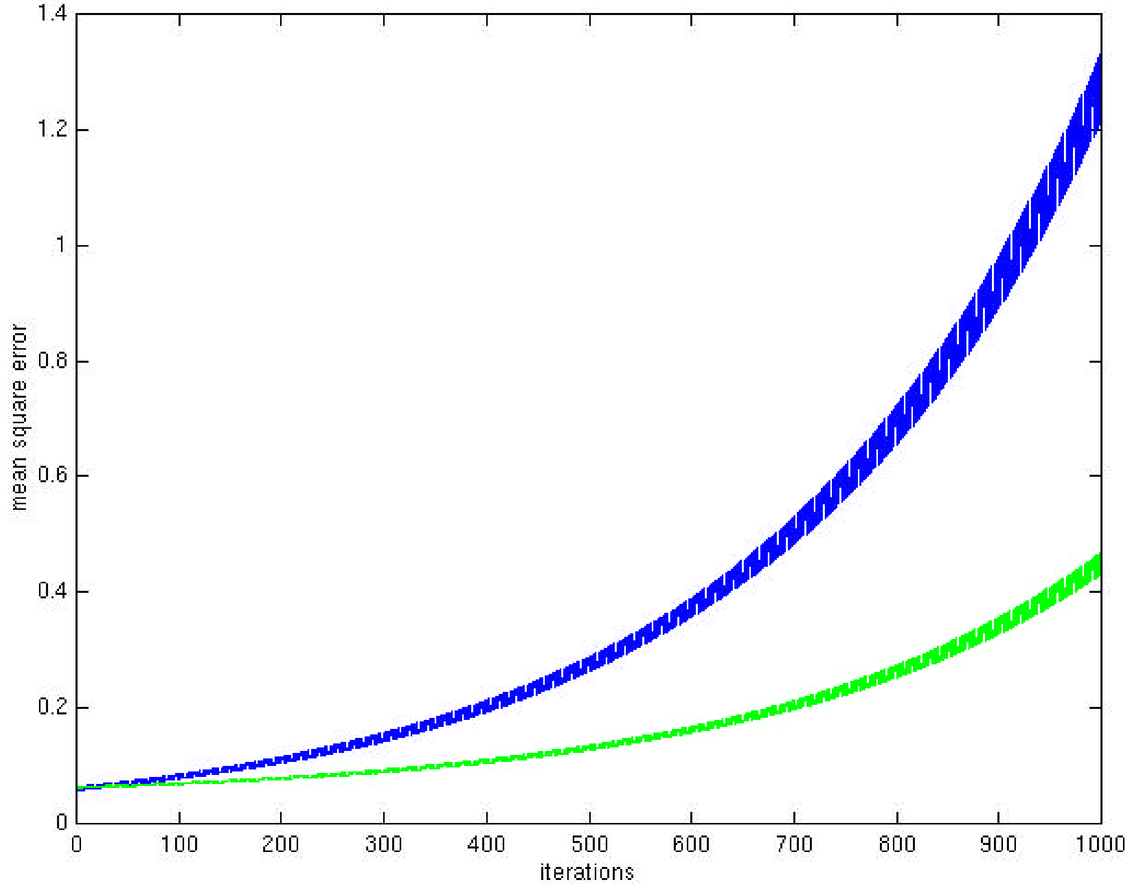

Figure 4: Comparison of the mean square error (MSE) of the sea surface height for the top layer. The blue line is the MSE when no data is assimilated. The green line is the MSE after assimilation of satellite altimetry data by the KBf algorithm.